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Meat quality characteristics of Tankwa goats from Carnarvon, Northern Cape

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Abstract

The aim of this study was to determine the post-mortem meat quality characteristics of extensively reared Tankwa goats to identify the most favourable age and sex for slaughter. Twenty-four goats, representing five groups, namely young intact males (G1), young females (G25), young castrates (G3), old males (G4), and females (G5), were selected directly from their natural grazing environment and slaughtered to evaluate meat quality characteristics. The *Musculus longissimus* and *Musculus semimembranosus* from the right side of each carcass were evaluated. Dressing percentage and chilling losses did not differ significantly between the groups. Ultimate pH at 24 hours after slaughter was higher for males than females. Meat colour, water-holding capacity, and sarcomere length did not differ between groups. Myofibril fragmentation length (MFL) was on average less than 40 µm and was shorter in younger animals. There were no significant differences in cooking loss and thawing loss for *M. longissimus* and *M. semimembranosus* between groups. There were no significant differences in Warner-Bratzler shear force (WBSF) between groups for meat from the *M. semimembranosus*. However, WBSF of the *M. longissimus* was higher in older animals. Overall, meat from these goats can be regarded as tender because meat with a WBSF below 5.5 is considered as tender.

Keywords: drought, myofibril fragmentation, protein source, sarcomere length, Warner-Bratzler shear force
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Introduction

Global warming will probably have a significant impact on livestock farming in the near future (Silanikove & Koluman, 2015). Goats are widely distributed around the world and have been a source of human nutrition since the beginning of human civilization (Webb *et al.*, 2005). Goats can be seen as 'walking factories' that produce food for humankind. Their short generation interval, high reproductive rate, ability to graze and utilize poor forages and walk long distances, and their smaller carcasses, which are more convenient to market and can be preserved and consumed over short periods are all factors that contribute towards the success of goats as meat-producing animals. Other factors include feasibility of herding by children and women because of flock instinct, and their ability to withstand droughts (Lebbie, 2004; Mahgoub *et al.*, 2011).

Consumers are interested in goats as a source of relatively lean meat, especially in developed countries with a high incidence of cardiovascular disease (Banskalieva *et al.*, 2000). The nutritional value of goat meat and milk is becoming recognized because of the medicinal cost of treating many human diseases (Aneato *et al.*, 2010). In terms of human nutrition, evidence indicates that goat meat can supply high-quality protein along with healthy fat (increased unsaturated fat / saturated fat ratio) and minimal cholesterol. In addition, the amino acid profile of goat meat is favourable in terms of its indispensable amino acids. The amino acid profile of goats shows a close resemblance to that of beef, pork, and lamb (Aneato *et al.*, 2010). Goat carcasses can have dissectible levels of meat as high as 66% to 68% (Murray *et al.*, 1997).

Feral goats from Tankwa Karoo National Park in the Northern Cape, South Africa, were identified in the 1900s, but now face the risk of extinction. Kotze *et al.* (2014) described this unique population of goats as having excellent mothering abilities, resistance to parasites, and ability to survive predators and harsh grazing

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conditions. These goats have survived and reproduced in one of the harshest climatic regions of South Africa because of their unique adaptive traits (Visser & Van Marle-Köster, 2018).

In the past, preference for goat meat in South Africa was relatively low because of traditional misconceptions of off-odours, off-flavours, unappealing colour, and toughness. For the meat of Tankwa goats to be acceptable according to market preferences, research into quality characteristics and improvement of goat meat has to become a priority. Meat quality attributes such as colour and tenderness determine the acceptability of the product (Pophiwa *et al.*, 2017). The aim of the current study was to determine the post-mortem meat quality characteristics of extensively reared Tankwa goats to establish the most favourable age and sex at slaughter for future marketing and to compare meat quality parameters with values obtained from other goat breeds.

Methods and materials

This project was approved by the Ethics Committee of the University of the Free State (UFS-AED2018/0066). Goats were sourced from Carnarvon, Northern Cape, Kareeberg Local Municipality in South Africa. Carnarvon lies 30.9600° S, 22.1549° E with an elevation of 1309 m, average temperature of 23 °C, average easterly wind speed of 18 km/h, and 18% humidity. At the time of sourcing, the population consisted of the limited number of approximately 300 animals of various sexes and ages (Figure 1). Animals were selected and weighed for market readiness from a population of 200–300 extensively reared goats. It was not possible to select at least five animals representative of all age and sex groups for this study. No formal records had been kept of these animals, and selection was based entirely on weight and permanent teeth eruption, because it is indicative of the animal's physiological age.

Figure 1 Herd of Tankwa goats at Carnarvon Research Station (Personal collection: Sako, 2019)

Figure 2 Selection of animals based on dental formula (Personal collection: Sako, 2019)

Twenty-four goats (n=24) were divided into five groups according to number of permanent teeth (Figure 2) and sex. Dental/age groups consisted of 0–2 teeth (n=15) and 4 teeth and above (n=9). Sex groups comprised intact males (n=9), castrates (n=5), and females (n=10) (Table 1).

Table 1 Grouping of animals by physiological age and sex for slaughter

	Intact males	Castrated males	Females
0–2 teeth: young	5	5	5
4 teeth and above: old	4		5

After selection, the goats were marked, weighed, and loaded onto a trailer. Animals were transported over 17 km from the research station to the abattoir (Carnarvon abattoir, reg no 9/53). On arrival, animals were rested for approximately 24 hours before slaughter. Fresh water and hay were available. On the day of slaughter, the goats were registered, queued, stunned electrically, stimulated electrically (as per standard slaughtering procedure), and put on the slaughter line. After evisceration, the carcasses were weighed to obtain warm carcass weight.

The pH readings were taken from both *M. longissimus* (L10–L11) and *M. semimembranosus* (most medial part) on the right-hand side of each carcass at 1, 2, 3, 6, 9, and 24 (pHu) hours after slaughter with a digital handheld Unitemp meat pH meter (Mettler Toledo, Johannesburg, South Africa). The pH meter was fitted with a polypropylene spear type gel electrode. The electrode was cleaned with distilled water after every temperature and pH reading. The pH meter was calibrated and verified after each pH interval throughout the sampling period with pH buffers of 4.01 and 7.00. Carcasses were classified according to the South African Carcass Classification system (SAMIC, 2006). Immediately after the first pH reading, carcasses were moved into a chiller that was set at 5 °C.

At 24 hours post-mortem, the carcasses were weighed to determine cold carcass weight. Dressing percentage and chilling loss of goat carcasses were calculated using these formulae (Islam *et al*., 2017):

Dressing percentage = $\frac{warm\ carcass\ weight}{live\ weight}\ x\ 100$ (Pophiwa *et al*., 2017)

Chilling loss = $\frac{warm\ carcass\ weight - cold\ carcass\ weight}{warm\ carcass\ weight}\ x\ 100$ (Pophiwa *et al*., 2017)

The entire, undamaged *M. longissimus* and *M. semimembranosus* from the right side of each carcass were removed 48 hours post-mortem. The samples were removed with a sharp knife, placed in plastic Ziploc bags, and stored in a large polystyrene container at approximately 5 °C. The samples were transported to the Agricultural Research Council – Animal Production Institute (ARC-API, Irene) where colour parameters and water-holding capacity were measured on fresh samples. For thaw loss, evaporation loss, cooking loss, sarcomere length, myofibril fragmentation lengths (MFL), and Warner-Bratzler shear force (WBSF), the remainder of the samples were frozen at -80 °C until ready for analyses.

Fresh cut samples of each muscle were allowed to bloom at room temperature (~22°C) for approximately 30 minutes. Instrumental colour values (CIE), L*, a*, b*, and hue angle were measured on exposed meat surfaces with a Minolta chroma meter (Minolta CR200, Minolta, Japan) (Young *et al*., 1999; O'Neill, 2016). Water-holding capacity was measured using the filter paper press method. Meat samples were placed on Whatman 4 filter paper and sandwiched at a constant pressure between two perspex plates. Areas were measured with a video image analyser (VIA) (soft imaging system, Olympus, Japan) (Honikel & Hamm, 1994).

For sarcomere length, samples from *M. longissimus* and *M. semimembranosus* were prepared according to the method of Hegarty & Naude (1970). Samples were homogenized in 15 mℓ distilled water with an ultra Turrax blender at low speed. A few droplets of homogenate were mounted on a slide, covered with a cover slip, and viewed immediately under an Olympus B340 system microscope at 31000x magnification, equipped with a CC12 video camera (Olympus, Tokyo, Japan) attached to a VIA (O'Neill, 2016; Ndakeva, 2018). Fifty sarcomeres per sample were measured and mean lengths were used for statistical analysis.

For myofibril fragment length (MFL; µm), sub-samples of ~3 g were removed from frozen samples and blended in cold potassium phosphate extraction buffer at 4 °C to arrest further proteolysis (Culler *et al.*, 1978) and determined according to the method of Heinze & Bruggeman (1944). Droplets of extracted MFL solution were mounted on microscope slides, covered with a cover slip, and viewed under a microscope attached to a VIA. One hundred myofibril fragments per sample were examined and measured at 40× magnification (O'Neill, 2016; Ndakeva, 2018).

Frozen samples were weighed and thawed overnight at a low temperature of 0–4 °C. Thawed samples were weighed again, and thawing loss was expressed as a percentage of pre-thawed weight. Meat samples were boiled in an oven at about 80 °C, allowed to cool down at room temperature, wiped to remove excess fluid, and weighed. Cooking loss was expressed as a percentage of pre-cooked weight.

Warner-Bratzler shear force (WBSF) on cooked and chilled meat samples was recorded. Cylindrical samples with a 12.5 mm core diameter were cored parallel to the grain of the cooked meat and sheared perpendicular to the fibre (six cores/sample where possible). Each core was sheared once through the centre, perpendicular to the fibre direction, with a Warner-Bratzler shear device mounted on a Universal Instron apparatus (model 4301, Instron Ltd, Buckinghamshire, UK) (crosshead speed 200 mm/min). Warner-Bratzler shear force was measured as the peak force (kg/12.5 mm Ɵ) averaged for the six cores. The reported value in kg represents the average of the peak force measurements of each sample (Ndakeva, 2018).

A 3 × 2 experimental design was used for the three sex groups and two age groups. There were only five groups because no older castrates were available. Repeated measures over time (pH) were analysed with

analysis of variance for contrast variables using the GLM procedure of SAS (2008) at a significance level of $P < 0.05$. Interaction between age and sex was taken into account. For all other observations, one-way analysis of variance and post-hoc Tukey tests of SAS (2008) were used to assess the effect of sex and age. P-values lower than 0.05 were considered significant. The results were reported as means ± standard error.

Results and Discussion

Goats were selected from a diverse group of extensively kept animals based on live weight and market readiness. The population size in the area was limited to 200 animals at the time of sampling. These animals had not been subjected to any form of selection strategy. Older animals were on average heavier ($P > 0.05$) than younger animals in terms of live weight, warm carcass weight, and cold carcass weight. The large degree of diversity was probably because the population varied morphologically to a great extent.

Dressing percentage and chilling loss are estimates of how much meat a carcass will yield. Dressing percentage is the relationship between the weight of the dressed carcass and live animal weight after the removal of the hide and internal organs. Table 2 shows the means for the effect of age and sex on live weight, warm carcass weight, cold carcass weight, dressing percentage, and chilling loss. Dressing percentages were 48.54 ± 1.83, 47.81 ± 1.90, 49.78 ± 1.46, 48.41 ± 2.17, 48.99 ± 1.53, and 47.82 ± 1.88 for young males, young females, young castrates, old males and old females, respectively, with no significant differences between groups. Average dressing percentage fell within the range reported by previous authors at between 47.81% and 49.78%. The mean dressing percentages of 47.5% for both Boer and indigenous goats were recorded by Pophiwa *et al.* (2017). Webb *et al*. (2014) reported that the average dressing percentage of goat carcasses varied between 50% and 55%, whereas Dhanda *et al*. (1999) reported that dressing percentage (based on full live weight) ranged between 41% and 47% and varied significantly between genotypes. Although the dressing percentage of goat carcasses is often low, it may be improved in this breed through selection strategies.

Chilling loss is the relationship between warm carcass weight and cold carcass weight and is an indication of the amount of water lost from a carcass in the first 24 to 48 hours post-mortem (Pophiwat *et al*., 2017). Conditions in the cooler and external fat thickness on a carcass have a direct impact on chilling loss. Average chilling losses for this study were 2.8%, 3.0%, 3.1%, 3.1%, and 3.0% for young males, young females, young castrates, old males, and old females, respectively. There was no significant difference in chilling loss between groups. The values in the present study agree with those obtained for other goat breeds. Chilling loss from goat carcasses is often high (up to 8%) (Webb *et al.*, 2014). Pophiwa *et al.* (2017) found that chilling loss was higher ($P < 0.01$) in carcasses of Boer goats compared with indigenous goats as documented by Webb *et al*. (2005) with chilling loss values of 2.15–2.62%, 2.28–3.04%, and 2.15–3.08%. The chilling loss from the carcasses of Tankwa goats compared favourably with that of other breeds.

Table 2 Mean (± SE) warm carcass weight, cold carcass weight, and dressing percentage of Tankwa goats

Groups[1]	Live weight (kg)	Warm carcass weight (kg)	Cold carcass weight (kg)	Dressing percentage (%)	Chilling loss (%)
All animals	44.04 ± 2.29	22.04 ± 1.16	21.38 ± 1.12	48.54 ± 0.37	2.98 ± 0.04
G1	38.60 ± 3.26	18.92 ± 1.42	18.38 ± 1.27	47.81 ± 0.85	2.84 ± 0.07
G2	39.60 ± 1.57	20.32 ± 0.91	19.72 ± 0.88	49.78 ± 0.65	2.95 ± 0.07
G3	56.20 ± 4.92	28.12 ± 2.62	27.26 ± 2.54	48.41 ± 0.97	3.06 ± 0.04
G4	43.75 ± 5.95	22.05 ± 2.87	21.38 ± 2.79	48.99 ± 0.76	3.08 ± 0.10
G5	42.00 ± 5.97	20.80 ± 3.13	20.18 ± 3.03	47.82 ± 0.84	2.97 ± 0.10
P-value	0.074	0.078	0.08	0.412	0.25

[1]G1: young intact males, G2: young females, G3: young castrate males, G4: old males, G5: old females

The high pHu values of the goat carcasses suggest that goats are generally prone to stress prior to slaughter (Webb *et al*., 2005). Table 3 shows the means for the effect of age and sex on pH in *M. longissimus* and *M. semimembranosus* from 1 to 24 hours post-mortem. Average pH in *M. longissimus* gradually dropped from 6.23 to 5.96. Average pH dropped from 6.35 to 5.95 in *M. semimembranosus*. These values corresponded with those found in other goat breeds by Dhanda *et al*. (2003), Kadim *et al*. (2004), and Simela *et al*. (2004). The pH in *M. longissimus* and *M. semimembranosus* at hours 3, 6, 9, and 12 was higher *(P* <0.05*)* for intact males than females, regardless of age.

Male animals are often more stressed than their female counterparts, as confirmed by Mota-Rojas *et al*. (2006), who indicated that the sex of the animal has an effect on the response of the animal to stress. Male animals are more excitable, aggressive, and stress sensitive than females, which explains the high post-mortem pH values in the muscle of male animals. The pH differences between males and females were more pronounced in *M. longissimus* than *M. semimembranosus*. The ultimate pH (pHu) of *M. longissimus* ranged between 5.72 and 6.18 with no significant differences between groups. Ultimate pH (pHu) of *M. semimembranosus* ranged between 5.76 and 6.19, with intact males having higher (P <0.05) pHu values compared with females and castrates, regardless of age. Once again, this can be explained by the fact that male animals are often more sensitive to stress prior to slaughter.

Ultimate pH (pHu) values were similar to those of various goat breeds reported by Webb *et al.* (2005). Similar results were also found by Dhanda *et al.* (1999), who found that pHu in *M. longissimus* of both Chevon and Capretto goats ranged between 5.6 and 5.8, with minor differences between genotypes. Average pHu values higher than the recommended pH (5.5) for desirable eating quality of red meat (Tarrant & Sherington, 1980) are indicative of ante-mortem stress, which can result in low quality meat. Simela *et al*. (2004) concluded that chevon with pHu higher than 6 tended towards dark, firm, and dry (DFD) meat. In bovine animals, meat with pH higher than 5.8 is classified as DFD (Tarrant & Sherington, 1980). Electrical stimulation of goat carcasses did not result in more rapid pH decline as expected, which is in contrast with the results from Kadim *et al.* (2010).

Table 3 Mean (±SE) pH from of *Musculus longissimus* and *Musculus semimembranosus* of Tankwa goats at 1–24 hours post-mortem

Groups[1]	Post-mortem pH					
	1 h	3 h	6 h	9 h	12 h	Ultimate
M. longissimus						
All animals	6.23 ± 0.04	6.03 ± 0.04	5.99 ± 0.05	5.93 ± 0.05	5.96 ± 0.05	5.96 ± 0.06
G1	6.36 ± 0.11	6.20^{a} ± 0.04	6.17^{a} ± 0.13	6.18^{a} ± 0.13	6.18^{a} ± 0.15	6.18 ± 0.15
G2	6.11 ± 0.02	5.91^{b} ± 0.04	5.80^{b} ± 0.04	5.69^{b} ± 0.02	5.77^{b} ± 0.02	5.82 ± 0.04
G3	6.21 ± 0.10	6.00^{ab} ± 0.06	5.95^{ab} ± 0.09	5.96^{c} ± 0.06	5.96^{c} ± 0.06	6.07 ± 0.11
G4	6.41 ± 0.12	6.16^{a} ± 0.09	6.17^{a} ± 0.12	6.08^{a} ± 0.10	6.09^{ab} ± 0.13	6.01 ± 0.19
G5	6.10 ± 0.02	5.91^{b} ± 0.11	5.88^{b} ± 0.09	5.78^{ab} ± 0.05	5.82^{ac} ± 0.03	5.72 ± 0.0
P-value	0.058	<0.05	<0.05	<0.05	<0.05	0.052
M. semimembranosus						
All animals	6.35 ± 0.04	6.14 ± 0.04	6.04 ± 0.05	5.99 ± 0.06	6.11 ± 0.04	5.95 ± 0.05
G1	6.27 ± 0.07	6.19 ± 0.11	6.15 ± 0.15	6.04^{a} ± 0.16	6.14 ± 0.11	6.02^{a} ± 0.11
G2	6.49 ± 0.04	6.14 ± 0.05	5.98 ± 0.10	5.81^{b} ± 0.07	6.11 ± 0.05	5.76^{b} ± 0.08
G3	6.28 ± 0.06	6.18 ± 0.03	6.16 ± 0.06	6.34^{ab} ± 0.06	6.23 ± 0.10	6.19^{a} ± 0.05
G4	6.24 ± 0.05	6.09 ± 0.12	6.02 ± 0.15	5.97^{b} ± 0.12	6.07 ± 0.06	6.02^{a} ± 0.12
G5	6.45 ± 0.16	6.10 ± 0.11	5.91 ± 0.09	5.79^{b} ± 0.10	6.02 ± 0.09	5.76^{b} ± 0.03
P-value	0.207	0.894	0.452	<0.05	0.539	<0.05

[1]G1: young intact males, G2: young females, G3: young castrate males, G4: old males, G5: old females
[a,b] Within a column, means with a common superscript were not significantly different

The surface appearance of meat determines how consumers perceive quality and influences purchasing decisions significantly (Carpenter *et al*., 2001). Meat colour is a function of a muscle's pigment content as well as light scattering properties. In the presence of oxygen, the purple ferrous haem pigment, myoglobin, forms a bright red, oxymyoglobin (MacDougall, 1982). At a high pHu of more than 6.0, myofibers hold a lot of water (Offer & Trinick, 1983). Higher myofibrillar volume prevents light from penetrating to a deeper depth and is scattered back to the eye (MacDougall, 1982).

Meat appears translucent and dark. At normal pHu values of about 5.5, myofibers hold less water and meat appears brighter and shinier (Ledward, 1992). Means for the effect of age and sex on meat A and D65 colour coordinates (L*, a*, b*, chroma, and HA) in *M. longissimus* and *M. semimembranosus* are indicated in Table 4. L* (lightness), a* (redness), and b* (yellowness) were in the range of 25.72–30.71, 16.85–20.94, and 11.04–13.28, respectively, with no significant difference between groups. These instrumental colour values compare well with reported values for Boer and indigenous goats of South Africa, as reported by Pophiwa *et al.* (2017), who found no significant breed differences in the colour of goat meat.

Table 4 Mean (±SE) D65 and colour coordinates (L*, a*, b*, chroma, and HA) of *Musculus longissimus* and *Musculus semimembranosus* of Tankwa goats

Groups[1]	D65 colour coordinates					A colour coordinates				
	L*	a*	b*	Chroma	Hue Angle	L*	a*	b*	Chroma	Hue Angle
M. longissimus										
All animals	27.43±0.48	11.39±0.24	10.80±0.30	15.73±0.35	43.31±0.62	29.41±2.44	17.51±1.52	12.01±1.69	21.29±1.91	34.31±3.41
G1	27.86±1.23	10.87±0.23	10.73±0.44	15.30±0.29	44.59±1.50	29.77±1.23	17.34±0.28	11.66±0.46	20.92±0.22	33.91±1.31
G2	28.63±0.95	11.79±0.53	11.96±0.58	16.81±0.76	45.78±0.71	30.71±1.02	17.92±0.71	13.28±0.70	22.32±0.90	36.55±1.14
G3	27.11±0.69	11.94±0.73	10.94±0.78	16.21±1.04	42.28±0.89	29.15±0.77	18.19±0.79	12.21±1.00	21.97±1.06	33.55±1.88
G4	25.74±1.91	11.17±0.26	9.84±0.84	14.94±0.72	40.98±1.96	27.64±1.96	17.19±0.22	11.04±0.94	20.53±0.63	32.48±2.13
G5	27.49±0.56	11.14±0.69	10.35±0.59	15.24±0.84	42.78±1.30	29.42±0.56	16.85±1.06	11.68±0.63	20.57±1.14	34.69±1.40
P-value	0.492	0.589	0.261	0.432	0.152	0.483	0.671	0.351	0.486	0.478
M. semimembranosus										
All animals	24.82±0.51	13.15±0.26	10.48±0.25	16.83±0.34	38.47±0.42	27.00±0.51	20.27±0.27	11.71±0.29	23.42±0.37	29.82±0.35
G1	26.49±1.46	12.20±0.51	10.25±0.58	15.95±0.71	39.93±1.13	28.54±1.49	19.80±0.62	11.05±0.63	22.69±0.82	29.03±0.88
G2	25.11±1.08	13.44±1.69	10.72±1.43	17.20±2.19	38.55±1.16	27.33±0.95	20.36±1.74	12.13±1.73	23.71±2.37	30.60±1.57
G3	24.96±2.25	12.82±1.28	10.33±1.28	16.48±1.73	38.70±1.95	27.09±2.15	19.94±1.03	11.47±1.59	23.02±1.67	29.71±2.28
G4	23.95±3.87	13.28±1.22	10.62±1.84	17.02±2.08	38.41±2.56	26.14±4.08	20.33±1.68	11.89±1.98	23.57±2.44	30.11±2.22
G5	23.44±0.68	14.01±0.63	10.53±0.68	17.54±0.88	36.73±0.94	25.72±0.73	20.94±0.97	12.02±0.65	24.16±1.14	29.72±0.67
P-value	0.376	0.242	0.98	0.635	0.173	0.46	0.724	0.785	0.768	0.734

[1]G1: young intact males, G2: young females, G3: young castrate males, G4: old males, G5: old females

Goat meat often appears darker than other types of red meat (Pophiwa *et al.*, 2017) as a result of different factors. Babiker *et al.* (1990) reported that goat meat is darker and redder when compared with lamb, mainly because goat carcasses have less intramuscular fat and Simela *et al*. (2004) explained that the innate stress responsiveness of goats contributes to darker meat. Dhanda *et al.* (1999) found that the colour of *M. longissimus* becomes significantly darker red with age. The present study does not agree with the previous authors as the results of the present study show an indirect proportional relationship between L* and age even though there was no significant difference. High pHu results in a darker meat and lower water holding capacity. High pHu (Table 3) as a possible result of transportation stress corresponds with higher a* values and lower L* values which means more redness and less lightness.

Water-holding capacity is an important economic factor that determines income received as carcasses are marketed per unit of mass. Stress and ante-mortem glycogen depletion in muscles result in meat with high pHu values. In addition, high pHu values, as were found in the current study, are detrimental for the conversion of muscle to good quality meat (Purchas *et al*., 1999). Water holding capacity in *M. longissimus* and *M. semimembranosus* for the groups ranged from 0.40–0.43% and from 0.39–0.41%, respectively, with no significant differences (Table 5). Ndakeva (2018) reported water holding capacity in *M. longissimus* muscle that ranged from 0.34–0.47% and in *M. semimembranosus* that ranged from 0.31–0.39 % with no significant differences for effect of goat ecotype and sex interaction. This concurs with the present study.

Table 5 Mean (±SE) water holding capacity of *Musculus longissimus* and *Musculus semimembranosus* of Tankwa goats

Groups[1]	Water holding capacity
M. longissimus	
All animals	0.42±0.05
G1	0.41±0.03
G2	0.40±0.04
G3	0.43±0.03
G4	0.42±0.09
G5	0.42±0.06
P-value	0.058
M. semimembranosus	
All animals	0.40±0.04
G1	0.41±0.06
G2	0.39±0.04
G3	0.40±0.05
G4	0.39±0.04
G5	0.40±0.02
P-value	0.207

[1]G1: young intact males, G2: young females, G3: young castrate males, G4: old males, G5: = old females

Sarcomere length is implicated in meat tenderness (Koohmaraie, 1994). As the supply of energy in the form of ATP from the conversion of glycogen to lactate is exhausted after death, the active heads of myosin molecules lock onto adjacent thin filaments. If sarcomeres are at a contracted length when *rigor mortis* sets in, an extra degree of toughness is superimposed on any intrinsic toughness (Swatland, 1982). Table 6 shows the means for the effect of age and sex on average sarcomere length (AVSARC) and median sarcomere length (MEDSARC) in *M. longissimus* and *M. semimembranosus.*

Average sarcomere length (AVSARC) in *M. longissimus* and *M. semimembranosus* ranged from 1.73–1.78 µm and from 1.74–1.85 µm, respectively, with no significant differences between age and sex groups. Simela *et al.* (2004) reported mean sarcomere lengths of 1.72 µm with minimum and maximum values of 1.24 and 2.15 µm for *M. semimembranosus* and no significant differences for age and sex. Kannan *et al.* (2006) reported sarcomere lengths of *M. longissimus* that ranged from 1.61–1.74 µm with no significance between treatments. Kadim *et al*. (2014) reported sarcomere lengths that ranged from 1.37–1.55 µm in *M. longissimus* because of cold shortening, which resulted in tougher meat.

Low temperature and high pH values in goat meat early post-mortem may reduce the activity of µ-calpain with little or no change in calpastatin activity, thereby minimizing the tenderization process during ageing (Kannan *et al.,* 2006). Myofibril fragment lengths (MFL) are associated with post-mortem proteolysis. During post-mortem storage, proteases weaken myofibrils, causing fragmentation and subsequent post-mortem tenderisation (Koohmaraie, 1994; Kannan *et al*., 2014; Ndakeva, 2018). Post-mortem proteolysis of muscle proteins influences meat tenderness of goat meat (Kannan *et al*., 2006; Gadiyaram *et al*., 2008). The means for the effect of age and sex on AVMFL and MEDMFL of *M. longissimus* and *M. semimembranosus* are shown in Table 6. There were significant differences between groups in *M. longissimus* for both the AVMFL and MEDMFL. Myofibril fragmentation lengths (MFL) of older animals and in both sexes were longer (P <0.05)

than in younger animals. There were no significant differences between groups for both AVMFL and MEDMFL in *M. semimembranosus*.

Results of the present study are similar to those of Ndakeva (2018) for both muscle groups. A myofibril fragmentation length (MFL) of less than 30 µm indicates that proteolytic activity has progressed well and is correlated with tenderness. Muscle with an MFL more than 40 µm is correlated with tough meat (Frylinck *et al*., 2009). Electrical stimulation improves goat meat tenderness by preventing cold shortening and causes physical disruption of the myofibrillar matrix, accelerating proteolysis (Savell *et al.,* 1978; Gadiyaram *et al.*, 2008). Myofibril fragmentation length in this study was on average less than 40 µm and indicated that proteolytic activity progressed well, especially in younger animals.

Table 6 Mean (±SE) average sarcomere lengths, median sarcomere lengths, average myofibril fragmentation lengths, and median myofibril fragmentation lengths of *Musculus longissimus* and *Musculus semimembranosus* of Tankwa goats

Groups[1]	AVSARC (µm)	MEDSARC (µm)	AVMFL (µm)	MEDMFL (µm)
M. longissimus				
All animals	1.76±0.09	1.75±0.09	29.42±4.92	27.19±4.67
G1	1.77±0.02	1.75±0.04	26.03^{a}±1.64	23.93^{a}±1.83
G2	1.73±0.07	1.73±0.08	26.78^{a}±3.66	24.41^{a}±2.40
G3	1.77±0.08	1.76±0.09	29.94^{b}±5.62	28.0^{b}±5.18
G4	1.78±0.17	1.77±0.17	34.69^{ab}±6.47	32.47^{ab}±6.73
G5	1.76±0.08	1.73±0.07	30.7^{b}±2.58	28.19^{b}±1.60
P-value	0.893	0.951	0.047	0.028
M. semimembranosus				
All animals	1.79±0.12	1.78±0.13	32.06±3.77	29.30±3.44
G1	1.74±0.14	1.73±0.14	31.44±6.30	29.14±5.91
G2	1.80±0.11	1.79±0.10	33.07±3.51	30.78±3.06
G3	1.82±0.15	1.82±0.14	31.50±3.53	28.52±3.12
G4	1.85±0.11	1.81±0.17	33.29±2.27	29.05±2.44
G5	1.76±0.13	1.76±0.13	31.26±2.99	28.94±2.42
P-value	0.711	0.846	0.891	0.889

^{a,b} Within a column, means with a common superscript did not differ with probability P <0.05

[1]G1: young intact males, G2: young females, G3: young castrate males, G4: old males, G5: old females

AVSARC: average sarcomere length; MEDSARC: median sarcomere length; AVMFL: average myofibril fragmentation length; MEDMFL: median myofibril fragmentation length

Water content in meat influences its juiciness or dryness. In combination with water, the melted lipids constitute a 'broth' which, when retained in meat, is released with chewing (Forrest *et al*., 1975; Schönfeldt *et al*., 1993b). Table 7 shows the means for the effect of age and sex on thawing, cooking loss, and evaporative loss of *M. longissimus* and *M. semimembranosus.* Because of the small sample size of *M. semimembranosus,* evaporation loss was not performed on this muscle group. Thawing loss ranged from 1.51% to 2.59% in *M. longissimus* with no significant differences between groups. On average, the thawing loss found in this study was higher than that reported by Schönfeldt *et al.* (1993b), which ranged from 0.25–0.69% with no significant difference between species. Thawing loss ranged from 2.93–5.12% in *M. semimembranosus* with no significant differences between groups. On average, thawing loss was higher in younger than older animals.

Cooking loss ranged from 16.37–19.14% in *M. longissimus* with no significant differences between groups. Kadim *et al.* (2004) reported cooking losses that ranged from 21.3–25.26% in *M. longissimus* of different goat breeds. Schönfeldt *et al.* (1993b) reported cooking losses that ranged from 15.54–18.61% in *M. longissimus*. Cooking loss for Dhanda *et al.* (1999) ranged from 34–39% in *M. longissimus* for the Capretto group, with significant differences among genotypes. Kadim *et al.* (2004) reported that differences in cooking loss were the result of differences in time and temperature of cooking, ultimate pH, and muscle use. There is less intramuscular fat in the meat of goats (Casey *et al.*, 1992), which explains more moisture loss during cooking and may give the impression of being poor in eating quality. Cooking loss ranged from 21.39–27.31% in *M. semimembranosus* with no significant differences between groups.

Statistical analysis between muscle groups was not performed in this study, but on average cooking loss was higher in *M. semimembranosus* than in *M. longissimus.* Kannan *et al.* (2000) also reported that on average cooking losses were higher in leg cuts and lower in loin cuts. Evaporation loss ranged from 15.57–17.59% with no differences between groups. Schönfeldt *et al*. (1993b) reported evaporation losses of 12.35–14.95%, both with no significance between the species. Moisture loss from goats in the present study was higher compared with the results of previous authors. This could be a result of intramuscular fat differences for the goat breeds, as explained by Casey *et al*. (1992). Meat from the Tankwa goat may taste less juicy in comparison with that of other breeds.

Table 7 Mean (±SE) thawing and cooking losses of *Musculus longissimus* and *Musculus semimembranosus* of Tankwa goats

Groups[1]	Thawing loss %	Cooking loss %	Evaporation loss%
M. longissimus			
All animals	2.07±1.15	18.06±3.98	16.67±3.68
G1	1.51±1.39	17.48±3.92	16.71±4.14
G2	2.47±1.02	18.56±5.24	17.01±4.83
G3	2.04±1.13	16.37±1.77	15.57±1.50
G4	1.67±1.21	18.91±4.63	17.59±4.56
G5	2.59±1.07	19.14±4.75	16.66±4.13
P-value	0.543	0.831	0.957
M. semimembranosus			
All animals	3.63±1.56	23.77±5.80	
G1	5.12±2.07	27.31±5.88	
G2	3.71±1.43	22.49±4.34	
G3	2.93±1.24	23.31±8.47	
G4	3.03±1.02	21.39±4.91	
G5	3.25±1.16	23.86±5.16	
P-value	0.159	0.626	

[1]G1: young intact males, G2: young females, G3: young castrate males, G4: old males, G5: old females

Warner-Bratzler shear force (WBSF) of meat is correlated with taste panel tenderness ratings (Schönfeldt *et al*., 1993a). Shear force of meat varies considerably as it is dependent on factors such as ante-mortem handling and handling of carcass post-mortem, the type of muscle, and method of sample preparation (Webb *et al*., 2005). The variations in shear force values reported by various researchers may arise from differences in nutrition, age, time and temperature of cooking, ultimate pH, and type of muscle. The means for the effect of age and sex on WBSF of *M. longissimus* and *M. semimembranosus* are shown in Table 8. Pophiwa *et al*. (2017), Ndakeva (2018) and Schönfeldt *et al*. (1993a) reported higher shear force values in the semimembranosus (SM) and lower shear force in the longissimus dorsi, which is similar to the results of the present study.

The differences in tenderness between muscles could be because SMs are involved in heavier contractions as they are located in limbs (Ndakeva, 2018). In the present study, WBSF ranged from young females (3.91) to young males (4.31) with significant differences between young and old animals. Warner-Bratzler shear force (WBSF) from *M. longissimus* was higher in older animals. The reason for higher WBSF values in males compared with females for all age groups is that males secrete testosterone, a precursor to cortisol, which is a stress hormone. Stress during the ante-mortem period has a negative effect on meat tenderness. It is not clear why the castrates had higher WBSF values in comparison to males and females.

Table 8 Mean (±SE) Warner-Bratzler shear force of *Musculus longissimus* and *Musculus semimembranosus* of Tankwa goats

Groups[1]	Warner-Bratzler shear Force (N)
M. longissimus	
All animals	3.81±0.84
G1	3.41^{a}±0.77
G2	3.39^{a}±0.89
G3	3.59^{b}±0.54
G4	4.85^{ab}±0.74
G5	4.03^{b}±0.59
P-value	0.039
M. semimembranosus	
All animals	4.07±0.86
G1	4.31±0.71
G2	3.91±1.10
G3	3.96±1.14
G4	4.19±1.06
G5	3.99±0.47
P-value	0.955

[a,b] Within a column, means with a common superscript did not differ with probability P <0.05

[1]G1: young intact males, G2: young females, G3: young castrate males, G4: old males, G5: old females

A taste test panel evaluation and Warner-Bratzler shear values by Savell et al. (1977) indicated that *M. longissimus* samples from electrically stimulated sides of three meat-producing species were significantly more tender than those from untreated sides. Shackelford *et al.* (1991) reported that a trained sensory panel and consumers regarded meat with a shear force value that was less than 5.5 as being tender. The present study reported a range of 3.91–4.31 for *M. semimembranosus* with no significant differences and 3.41–4.85 with significant differences for *M. longissimus*. The results of the present study show an average of below 5.5 for both the *M. longissimus* and *M. semimembranosus*, which is required for tender meat. According to (Shackelford et al., 1991) therefore, this meat is tender.

Conclusion

The meat quality parameters of the Tankwa goat compared well with the results from other goat breeds. Age was the decisive factor influencing meat quality in Tankwa goats. Age had a significant effect on muscle acidification, post-mortem proteolysis, and Warner-Bratzler shear force, with younger animals showing more favourable values. Sex had a significant effect on Warner-Bratzler shear force in which males and castrates had higher values than females.

Thus, it can be concluded that young females have the most tender meat. Further research should be conducted to determine the best age for slaughter to obtain the desired meat quality characteristics. Research into muscle fibre type, carcass composition, and enzymes could contribute to the quantification of meat quality characteristics of Tankwa goats.

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Authors' contribution

Animal selection and sample collection by TS, HAO, and TS. The paper was conceptualised and drafted by HAO.

Conflict of interest declaration

The authors declare there is no conflict of interest.

References

Anaeto, M., Adeyeye, J.A., Chioma, G.O., Olarinmoye, A.O. & Tayo, G.O., 2010. Goat products: Meeting the challenges of human health and nutrition. Agr. Biol. J. N. Am. 1(6), 1231-1236.

Babiker, S.A., El Khider, I.A. & Shafie, S. A., 1990. Chemical composition and quality attributes of goat meat and lamb. Meat Science 28(4), 273-277. DOI: 10.1016/0309-1740(90)90041-4

Banskalieva, V., Sahlu, T.A. & Goetsch, A.L., 2000. Fatty acid composition of goat muscles and fat depots: A review. Small Rumin. Res. *37*(3), 255-268. DOI: 10.1016/s0921-4488(00)00128-0

Carpenter, C.E., Cornforth, D.P. & Whittier, D., 2001. Consumer preferences for beef color and packaging did not affect eating satisfaction. Meat Science 57(4), 359-363. DOI: 10.1016/s0309-1740(00)00111-x

Casey, N.H., 1992. Goat meat in human nutrition. In: Proceedings of the V International Conference on Goats, New Delhi, India, 1992.

Culler, R.D., Smith, G.C. & Cross, H.R., 1978. Relationship of myofibril fragmentation index to certain chemical, physical, and sensory characteristics of bovine *longissimus* muscle. J. Food Sci. 43(4), 1177-1180. DOI: 10.1111/j.1365-2621.1978.tb15263-x

Dhanda, J.S., Taylor, D.G., McCosker, J.E. & Murray, P.J., 1999. The influence of goat genotype on the production of Capretto and Chevon carcasses. 1. Growth and carcass characteristics. Meat Science 52(4), 355-361. DOI: 10.1016/s0309-1740(99)00016-9

Forrest, J.C., Aberle, E.D., Hedrick, H.B., Judge, M.D. & Merkel, R.A., 1975. Principles of meat science. WH Freeman & Co., Reading, UK. DOI: 19751431595

Frylinck, L., Van Wyk, G.L., Smith, T.P.L., Strydom, P.E., van Marle-Köster, E., Webb, E.C., Koohmaraie, M. & Smith, M.F., 2009. Evaluation of biochemical parameters and genetic markers for association with meat tenderness in South African feedlot cattle. Meat Science 83(4), 657-665. DOI: 10.1016/j.meatsci.2009.07.016

Gadiyaram, K.M., Kannan, G., Pringle, T.D., Kouakou, B., McMillin, K.W. & Park, Y.W., 2008. Effects of post-mortem carcass electrical stimulation on goat meat quality characteristics. Small Rumin. Res. 78(1-3), 106-114. DOI 10.1016/j.smallrumres.2008.05.013

Hegarty, P.V. & Naudé, R.T., 1970. The accuracy of measurement of individual skeletal muscle fibres separated by a rapid technique. Lab. Pract. 9(2), 161-164.

Heinze, P.H. & Bruggeman, D., 1994. Ageing of beef: Influence of two ageing methods on sensory properties and myofibrillar proteins. Sci. Aliment. 14, 387-399.

Islam, R., Redoy, M.R.A., Shuvo, A.A.S., Sarker, M.A.H., Akbar, M.A. & Al-Mamun, M., 2017. Effect of pellet from total mixed ration on growth performance, blood metabolomics, carcass, and meat characteristics of Bangladeshi garole sheep. Progress. Agric. 28(3), 222-229. DOI: 10.3329/pa.v28i3.34659

Kadim, I.T., Mahgoub, O., Al-Marzooqi, W. & Khalaf, S., 2010. Effect of transportation and low voltage electrical stimulation on meat quality characteristics of Omani sheep. Journal of Agricultural and Marine Sciences 15, 1-8. DOI:10.24200/jams.vol15iss0pp1-8.

Kadim, I.T., Mahgoub, O., Al-Ajmi, D.S., Al-Maqbaly, R.S., Al-Saqri, N.M. & Ritchie, A., 2004. An evaluation of the growth, carcass and meat quality characteristics of Omani goat breeds. Meat Science 66(1), 203-210. DOI: 10.1016/S0309-1740(03)00092-5

Kannan, G., Terrill, T.H., Kouakou, B., Gazal, O.S., Gelaye, S., Amoah, E.A. & Samake, S., 2000. Transportation of goats: Effects on physiological stress responses and live weight loss. J. Anim. Sci. 78(6), 1450-1457. DOI:10.2527/2000.7861450x

Kannan, G., Lee, J.H. & Kouakou, B. 2014. Chevon quality enhancement: Trends in pre-and post-slaughter techniques. Small Rumin. Res. 121(1), 80-88. DOI: 10.1016/j.smallrumres.2014.03.009

Kannan, G., Gadiyaram, K.M., Galipalli, S., Carmichael, A., Kouakou, B., Pringle, T.D., McMillin, K.W. & Gelaye, S., 2006. Meat quality in goats as influenced by dietary protein and energy levels and post-mortem aging. Small Rumin. Res. 61(1), 45-52. DOI: 10.1016/j.smallrumres.2005.01.006

Koohmaraie, M., 1994. Muscle proteinases and meat aging. Meat Science 36(1-2), 93-104. DOI: 10.1016/0309-1740(94)90036-1

Kotze, A., Grobler, J.P., van Marle-Köster, E., Jonker, T. & Dalton, D.L., 2014. The Tankwa Karoo National Park feral goat population: A unique genetic resource. S. Afr. J. Anim. Sci. 44(1), 43-48. DOI:10.4314/sajas.v44i1.6

Lebbie, S.H.B., 2004. Goats under household conditions. Small Rumin. Res. 51(2), 131-136. DOI:10.1016/j.smallrumres.2003.08.015

Ledward, D.A., 1992. Colour of raw and cooked meat. Special Publication - Royal Society of Chemistry 106, 128-128.

MacDougall, D.B., 1982. Changes in the colour and opacity of meat. Food Chem. 9(1-2), 75-88. DOI: 10.1016/0308-8146(82)90070-X

Mahgoub, O., Kadim, I.T. & Webb, EC., 2011. Goat meat production and quality. CABI, Oxfordshire, UK.

Mota-Rojas, D., Becerril, M., Lemus, C., Sánchez, P., González, M., Olmos, S.A., Ramírez, R. & Alonso-Spilsbury, M., 2006. Effects of midsummer transport duration on pre-and post-slaughter performance and pork quality in Mexico. Meat Science, 73(3), 404-412. DOI: 10.1016/j.meatsci.2005.11.012

Murray, P.J., Dhanda, J.S., & Taylor, D.G., 1997. Goat meat production and its consequences for human nutrition. In Proceedings: Nutrition Society of Australia 21, 28-36. DOI: 10.5713/ajas.2003.1842

Ndakeva, N., 2018. Effects of goat ecotype and sex on post-mortem muscle energy status and meat quality. MSc Agric dissertation, University of Pretoria, South Africa.

O'Neill, H.A. 2016. The influence of catecholamines on energy metabolism, beef colour, and tenderness in three commercial beef breeds. Doctoral dissertation, University of Pretoria, South Africa.

Offer, G. & Trinick, J., 1983. On the mechanism of water holding in meat: The swelling and shrinking of myofibrils. Meat Science 8(4), 245-281. DOI: 10.1016/0309-1740(83)90013-X

Pophiwa, P., Webb, E.C. & Frylinck, L., 2016. Meat quality characteristics of two South African goat breeds after applying electrical stimulation or delayed chilling of carcasses. Small Rumin. Res. 145, 107-114. DOI: 10.1016/j.smallrumres.2016.10.026

Pophiwa, P., Webb, E.C. & Frylinck, L., 2017. Carcass and meat quality of Boer and indigenous goats of South Africa under delayed chilling conditions. S. Afr. J. Anim. Sci. 47(6), 794-803. DOI:10.4314/sajas.v47i6.7

Pophiwa, P., 2017. Effects of electrical stimulation and delayed chilling on carcass and meat quality of indigenous and Boer goats in South Africa. Doctoral dissertation, University of Pretoria, South Africa.

Purchas, R.W., Yan, X. & Hartley, D.G., 1999. The influence of a period of ageing on the relationship between ultimate pH and shear values of beef *M. longissimus thoracis*. Meat Science *51*(2), 135-141. DOI: 10.1016/s0309-1740(98)00111-9

South African Meat Industry Company (SAMIC), 2006. http://samic.co.za; accessed February 2021.

Savell, J.W., Dutson, T.R., Smith, G.C. & Carpenter, Z.L., 1978. Structural changes in electrically stimulated beef muscle. J. Food Sci. 43(5), 1606-1607. DOI: 10.1111/j.1365-2621.1978.tb02553.x

Schönfeldt, H.C., Naude, R.T., Bok, W., Van Heerden, S.M., Sowden, L. & Boshoff, E., 1993. Cooking-and juiciness-related quality characteristics of goat and sheep meat. Meat Science 34(3), 381-394. DOI: 10.1016/0309-1740(93)90085-V

Schönfeldt, H.C., Naude, R.T., Bok, W., van Heerden, S.M., Smit, R. & Boshoff, E., 1993. Flavour- and tenderness-related quality characteristics of goat and sheep meat. Meat Science 34(3), 363-379. DOI: 10.1016/0309-1740(93)90084-U

Shackelford, S.D., Morgan, J.B, Cross, H.R. & Savell, J.W., 1991. Identification of threshold levels for Warner-Bratzler shear force in beef top loin steaks. Muscle Foods 2(4), 289-296. DOI: 10.1111/j.1745-4573.1991.tb00461.x

Silanikove, N. & Koluman, N., 2015. Impact of climate change on the dairy industry in temperate zones: predications on the overall negative impact and on the positive role of dairy goats in adaptation to earth warming. Small Rumin. Res. 123(1), 27-34. DOI: 10.1016/j.smallrumres.2014.11.005

Simela, L., Webb, E.C. & Frylinck, L., 2004. Effect of sex, age, and pre-slaughter conditioning on pH, temperature, tenderness, and colour of indigenous South African goats. S. Afr. J. Anim. Sci. 34(5).

Swatland, H.J., 1982. Quantitative histochemistry of muscle enlargement and post-mortem metabolism. In: Muscle hypertrophy of genetic origin and its use to improve beef production. Springer, Dordrecht. pp. 278-305. DOI: 10.1007/978-94-009-7550-7_25

Tarrant, P.V. & Sherington, J., 1980. An investigation of ultimate pH in the muscles of commercial beef carcasses. Meat Science 4(4), 287-297. DOI: 10.1016/0309-1740(80)90028-5

Visser, C. & van Marle-Köster, E., 2018. The development and genetic improvement of South African Goats. Goat Science 19. DOI: 10.5772/intechopen.70065

Webb, E.C., 2014. Goat meat production, composition, and quality. Anim. Front. 4(4), 33-37.
Webb, E.C., Casey, N.H. & Simela, L., 2005. Goat meat quality. Small Rumin. Res. 60(1-2), 153-166. DOI: 10.1016/j.smallrumres.2005.06.009
Young, O.A., Priolo A., Simmons, N.J., & West, J., 1999. Effects of rigor attainment temperature on meat blooming and colour on display. Meat Science 52(1), 47-56. DOI: 10.1016/s0309-1740(98)00147-8